The layered control strategy for the converter dominated DC Microgrid

Xiaotong Xu, Huiqing Wen and Kai Zheng
Department of electrical and electronic engineering
Xi'an Jiaotong-Liverpool University
Suzhou, China

***Abstract*—DC Microgrid has drawn more and more attention in the distribution system as it is easier for connecting DC sources and loads. This paper presents a layered control strategy with three levels for regulating the voltage and balancing the power for DC Microgrid consisting of different kinds of distributed generations and loads. DC voltage value is defined as a signal to change the control mode, and each converter operates independently without the need to communicate with each other. Therefore, the configuration of DC Microgrid is simplified. The validity of this control strategy is simulated through PSCAD under different operating conditions, such as changing the wind speed, the irradiation, and the load value or main grid failure case. From analyzing the simulation result, it can be seen that this layered control strategy is effective, and every converter responds quickly and correctly to the variation.**

***Index Terms*—DC Microgrid; layered control; primary control; secondary control; tertiary control**

I. INTRODUCTION

With the consuming of fossil fuels, renewable energy is exploited and utilized more and more in recent years, so the problem of climate change and environmental issues are reduced. For the purpose of using the distributed generation (DG) with renewable resources easily in the electrical power system, Microgrid is proposed [1]-[2]. Although the Microgrid is not widely used in our daily life nowadays, it will change the configuration of power system in the future because it is more flexible and efficient, and the reliability of the power supply can be improved as the Microgrid can operate either in the grid-connected or islanded mode [3]-[4]. In order to ensure the reliable and efficient operating of the Microgird, suitable control strategies should be applied to the DG [5].

The Microgrid can be divided into AC Microgrid and DC Microgrid. Compared with AC Microgrid, DC Microgrid has many advantages. For a DC Microgrid, the control strategy is simpler because the control of frequency and reactive power is ignored, and it is more convenient for some kinds of DG (photovoltaic cell, batteries) to connect to the DC Microgrid. What is more, the efficiency and power quality is high, and the cost is low for DC Microgrid. Therefore, DC Microgrid has drawn much attention among researchers [6]-[7].

Centralized and decentralized control are two kinds of control strategies for DC Microgrid. The centralized control strategy relies on the energy control center to regulate all Microgrid terminals. However, the Microgrid is not reliable because of this centralized structure, and it is hard to expand the Microgrid for future development [8]-[9]. These problems can be solved by applying the decentralized control strategy. Making use of the local information, different control decisions can be made for different terminals. The basic control methods for decentralized control strategy are voltage/current and voltage/power droop control schemes [10]-[11]. Although the reliability is improved, the DC Microgrid is inflexible as the result of the unchangeable droop setting under different conditions [12].

In order to overcome these problems, a layered control strategy is applied to DC Microgrid in this paper. Based on different DC voltage values, the layered control strategy are categorized into primary control, secondary control and tertiary control. For each control level, at least one converter is responsible for regulating the voltage and balancing the power. This layered control strategy is tested through establishing a DC Microgrid model in the PSCAD, and the simulation result shows that this strategy is effective both in the grid-connected and islanded mode.

II. THE CONFIGURATION OF DC MICROGRID

A DC Microgrid system is shown in Fig.1, and it includes the distributed generator (the photovoltaic cell, the wind turbine), the storage device (the battery), the load and related converters. The operating mode of DC Microgrid is transformed by changing the state of the PCC. When PCC closes, DC Microgrid is in the grid-connected mode, and loads are supplied by the main grid and distributed generators. When DC Microgrid should be isolated from the main grid due to main grid failure, the PCC opens, and distributed generators generate power to meet the load demand. Because the power flow in this system is DC power, so the AC power from the main grid, the wind turbine and AC load should be converted to DC power, and then these elements are connected to the DC bus. In order to ensure the stability and power supply of the system, layered control which is based on measuring the DC bus voltage is used. By applying different control methods at different DC bus voltage, this DC Microgrid can operate in different cases.

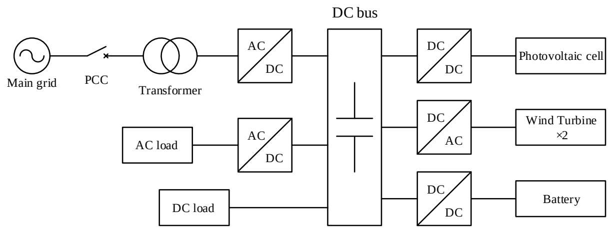


Fig.1: The configuration of DC Microgrid

III. THE LAYERED CONTROL STRATEGY

The DC Microgrid is unstable when DC bus voltage fluctuates, so DC bus voltage can be used to monitor the stability of the Microgrid system. Based on different DC bus voltage, the layered control strategy is divided into three levels, including the primary control, the secondary control and the tertiary control. The control strategy for different elements in the Microgrid are not same, but at least one component is responsible for each control level. Different control levels are defined by the DC bus voltage as shown in Fig.2.

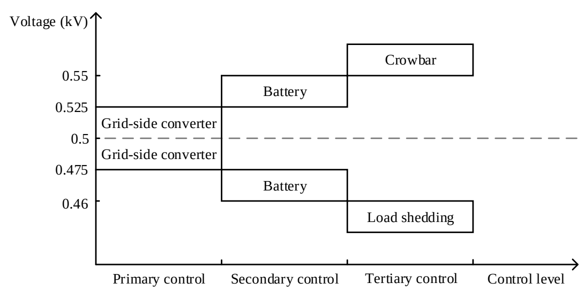


Fig.2: The layered control strategy

A. The primary control

The rated DC voltage for the DC Microgrid is set to 0.5 kV. If the voltage variation ΔV_{dc} is smaller than 0.05kV, the primary control will work, and the DC voltage is adjusted by the grid-side converter. As shown in Fig.3 (a), the active power is controlled by regulating the current of d axis, and the current reference value of d axis is obtained from the difference between the DC voltage and the reference value. As a result of using the unity power factor, the inner current control loop regulates the reactive power by adjusting the grid current of q axis to zero. The battery is charged with constant power, so current control is applied.

B. The secondary control

When the voltage variation ΔV_{dc} is more than 0.05kV, the grid-side converter is unable to control the DC voltage. In this case, the battery takes the place of the grid-side converter to regulate the DC voltage, so the battery changes to voltage regulation mode from constant current charge mode, and the output of the gird-side converter is equal to zero. The power balance of the system is controlled by adjusting the charging or discharging current of the battery, and the DC side voltage of the battery can be expressed as

$$U_{DC\_B} = U_{DC\_Bref} - \frac{0.03}{I_{B\max}} \cdot I_{DC\_B} \tag{1}$$

Where I_{Bmax} refers to the maximum current of the DC bus, and U_{dc_Bref} is set to 0.475kV or 0.525kV according to the hierarchical control strategy. If the DC side current I_{DC_B} is positive, the battery will discharge power to the load. The battery is charged from the grid when I_{DC_B} is negative. The relationship between the battery voltage (U_B) and current (I_B) is

$$I_B = \frac{U_{DC\_B}}{U_B} \cdot I_{DC\_B} \tag{2}$$

As presented in Fig.3 (b), the battery is controlled by the double closed loop, and I_{Bref} can be calculated from these equations.

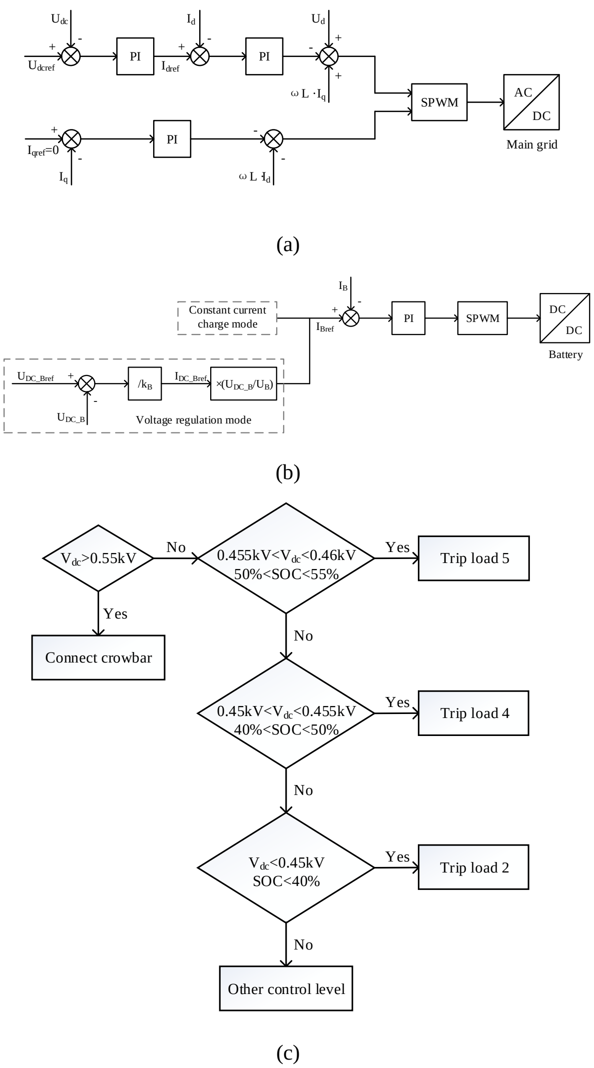


Fig.3: The control strategies of electrical components. (a) The grid-side converter; (b) The battery; (c) The load.

TABLE I. THE PARAMETER OF COMPONENTS IN DC MICROGRID

Main grid		***Rated voltage***	0.3 kV
Wind turbine		***Rated wind speed***	10 m/s
		Rotor radius	10 m
		Rated power	60 kVA
Photovoltaic cell		***Reference irradiation***	1000 W/m^2
		Reference cell temperature	25 ℃
		Array size	20 × 20
Battery		***Inductance***	0.1 mH
Load	**DC load**	***Load 1***	12 Ω
		Load 2	24 Ω
	AC load	***Load 3***	0.04 MW
		Load 4	0.05 MW
		Load 5	0.02 MW

C. The tertiary control

The tertiary control is applied when the DC voltage goes up to 0.55kV or reduces to 0.46kV, and DC Microgrid operates in the islanded mode. According to different voltage values, two cases are considered. If DC voltage is more than 0.55kV, which means the power supply is much bigger than the load demand, the crowbar should be added to DGs so as to cut down the output power. Another case is that the power generated by DGs cannot supply the large load in the DC Microgrid, and the DC voltage is below 0.46kV. The control strategy for this case is to separate loads from the DC bus. However, the power supply of some sensitive loads must be guaranteed in this process, so insensitive loads are disconnected from the system firstly. What is more, for the purpose of protecting the battery, the SOC value of the battery also needs to be considered. When the SOC is smaller than 55%, load shedding process starts. The detailed setting for tertiary control can be seen from Fig.3 (c).

IV. SIMULATION RESULTS AND ANALYSIS

In order to test the feasibility of the layered control strategy, a DC Microgrid system which is based on the configuration in Fig.1 is built in the PSCAD, and the parameter of the system is shown in Table Ⅰ.

A. The primary control

At the beginning, the wind speed is 4m/s, and the irradiation of the photovoltaic cell is 800 W/m^2. The output power of DGs are 0.5MW. All loads except load 4 and load 5 are connected to the DC bus, and the load demand is about 0.028MW. Because the DG output is larger than the load demand, so surplus power is absorbed by the main grid. Load 4 and load 5 are added to DC Microgrid at 1s, and the load demand increases to 0.1 MW. In this case, the active power of DGs is not enough to supply the large load, so the main grid should compensate the rest of the power. The wind speed increases to 8m/s at 2s, and the output power of one wind turbine changes from 0.005MW to 0.045MW. Meanwhile, the irradiation of the photovoltaic cell becomes 1000 W/m^2, so the output power of photovoltaic cell is 0.027MW. The load demand and DGs' output are balanced approximately from 2s to 3s, and the DC voltage can be regulated to 0.5kV under the primary control in the whole process.

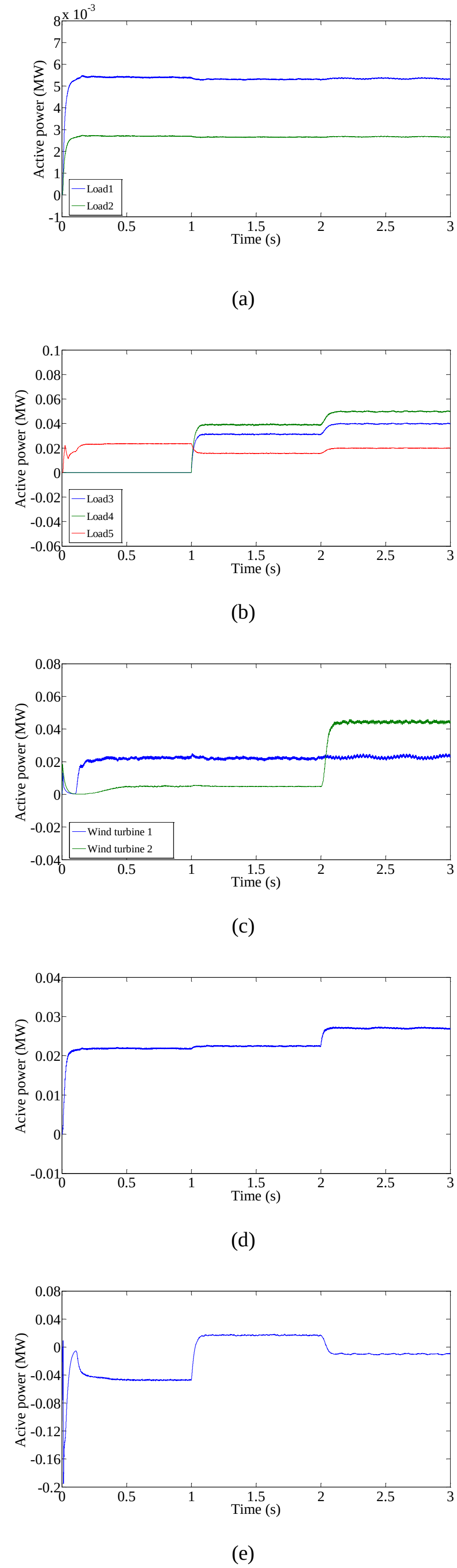
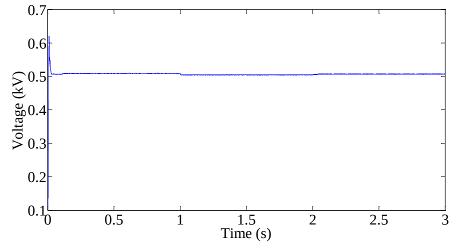


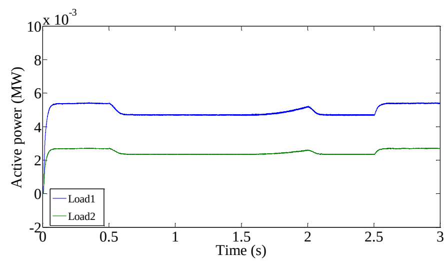
Fig.4: The active power under primary control. (a) DC loads; (b) AC loads; (c) Wind turbines; (d) The Photovoltaic cell; (e) The main grid.



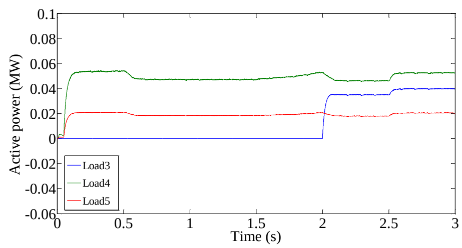
(b)

Fig.5: The DC voltage of the main grid under primary control.

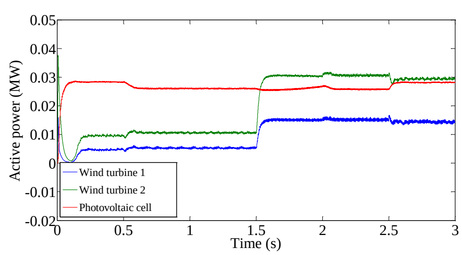
B. *The secondary control*



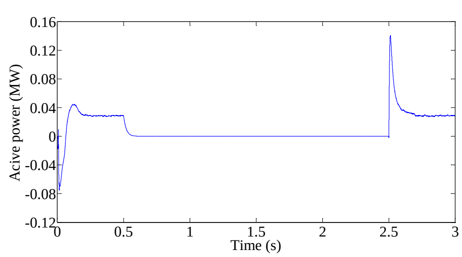
(a)



(b)

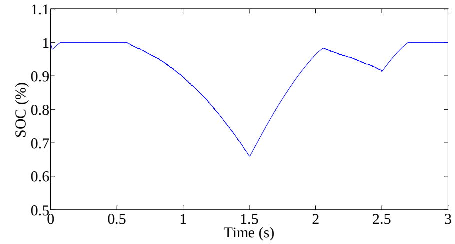


(c)

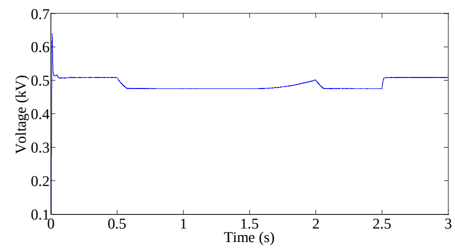


(d)

Fig.6: The active power under secondary control. (a) DC loads; (b) AC loads; (c) DGs; (d) The main grid.



(a)



(b)

Fig.7: The SOC of battery and DC voltage of the main grid under secondary control. (a) The SOC of battery; (b) The DC voltage of main grid.

Before 0.5s, DC Microgrid operates in the grid-connected mode, and the system is controlled by the primary level. Except for load 3, other DC and AC loads are connected to the system, and these loads are supplied by DGs and the main grid. DC Microgrid changes to islanded mode as a big disturbance happens in the main grid at 0.5s. Because the main grid cannot generate power to the load any more, so the battery replaces the main grid to control the power balance, and the battery discharges power to the load in this condition. Therefore, the SOC decreases, and the DC voltage can be kept at 0.475kV. At 1.5s, the wind speed increases from 5m/s to 7m/s, thus the output power of DGs rises, and the redundant energy is used for charging the battery. Load 3 is added to DC bus at 2s, then the battery discharges again until DC Microgrid is reconnected to the main grid at 2.5s, the DC bus voltage recover to the normal value.

C. *The tertiary control*

Fig.10 to Fig.12 shows the simulation results of DC Microgrid under the tertiary control. The Microgrid operates in the grid-connected mode before 0.5s, and all loads are connected to the system. The wind speed is 5m/s, and the irradiation of the photovoltaic cell is 700 W/m^2. Because the output power of DGs is too small to meet the load demand, so most of the load is supplied by the main grid. The DC Microgrid is separated from the main grid at 0.5s, then the battery should change to the voltage regulation mode, and discharge power to the load. When DC voltage decreases to 0.46kV, and the SOC of the battery is below 55%, insensitive loads (load 5, load 4 and load 2) are disconnected from the grid in sequence. Therefore, DC voltage stops dropping. Then the output power of DGs increases at 1.5s, and the DC voltage goes up slowly. Meanwhile, insensitive loads is reconnected to the system with the increasing of DC voltage, and the battery begins to charge power. At 2.2s, the DC Microgrid is reconnected to the main grid, and DC voltage rises to 0.5kV.

The operating condition of the crowbar is similar to the load shedding process. If the power generated by DGs is much more than the load demand, DC voltage will increase. When DC voltage exceeds 0.55kV, the crowbar should be added to DGs in order to limit the output power of DGs, so DC voltage remains at 0.55kV. Because of the space limitation, the simulation results is not shown in this paper.

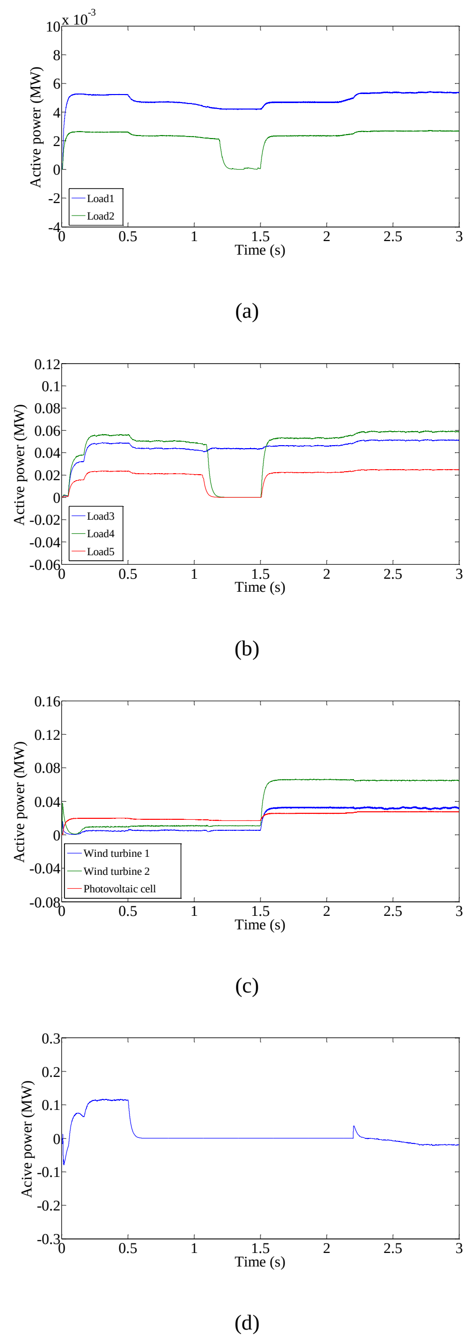


Fig.8: The active power under tertiary control. (a) DC loads; (b) AC loads; (c) DGs; (d) The main grid.

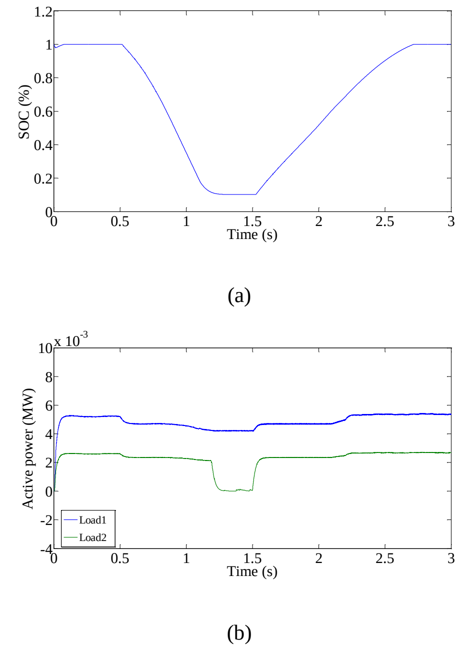


Fig.9: The SOC of battery and DC voltage of the main grid under tertiary control. (a) The SOC of battery; (b) The DC voltage of main grid.

V. Conclusion

This paper focus on analyzing the layered control in DC Microgrid. The control strategy is divided into three levels which is based on different DC voltage, and the feasibility of the control strategy is tested by building a DC Microgrid model in the PSCAD. From the simulation result, it can be concluded that the layered control strategy can regulate DC voltage, and balance the power flow successfully under different conditions.

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